The Extragalactic Distance Scale Key l'reject VII. The Discovery of Cepheids in the Leo 1 group Galaxy NGC 3351 Using the 1 Iubble Space Telescope[1]

John A. Graham

1)epartment of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC 20015, USA

Randy L. Phelps & Wendy L. Freedman

Carnegie Observatories, Pasadena CA 91101, USA

Abhijit Saha & Laura Ferrarese

Space Telescope Science Institute, Baltimore MD 21218, USA

Peter 1]. Stetson

National Research Council of Canada, Herzberg Institute of Astrophysics, 1)ominion Astrophysical Observatory, Victoria, 1 3C V8X 4M6, Canada

Barry F. Madore, N. A. Silbermann & Shoko Sakai

I]'AC, California Institute of Technology, Pasadena CA 91125, USA

Robert C. Kennicutt, Paul Harding, Fabio Bresolin & Anne Turner

Steward Observatories, University of Arizona, '1 'ucson AZ 85721, USA

Jeremy R. Mould & 1)aya h4 . Rawson

Mount Stromlo and Siding Spring Observatories, Institute of Advanced Studies, Australian N ational University, Weston Creek, ACT 2611, Australia

Holland C. 1"01"[1

Johns Hopkins University and Space Telescope Institute, Baltimore MD 21218, USA

John G. Hoessel & Mingsheng Han

University of Wisconsin, Madison, WI, 53706, USA

John P. Huchra & Lucas M. Macri

Harvard Smithsonian Center for Astrophysics, Cambridge, MA 02138, USA

Shaun M. Hughes

Royal Greenwich Observatory, Cambridge CB3 0HA, UK

Garth D. Illingworth & Daniel D. Kelson

Lick Observatory, University of California, Santa Cruz CA 95064, USA

[1] Based on observations with the NASA/ESA *Hubble Space Telescope*, obtained at the Space Telescope Science Institute, operated by AURA, Inc. under NASA contract No. NAS5-26555.

Received ____________________, accepted ____________________

ABSTRACT

We report of the discovery and properties of Cepheid variable stars in the barred spiral galaxy NGC 3351 which is a member of the Leo 1 group of galaxies. NGC 3351 is one of 18 galaxies being observed as part of the Hubble Space Telescope (HST) Key Project on the Extragalactic Distance Scale which aims to determine the Hubble Constant to 10% accuracy. our analysis is based on observations made with the Wide Field and Planetary Camera 2 during 1994 and early 1995. The Leo I group contains several bright galaxies of diverse types and is very suitable for linking together a number of secondary calibrators which can be employed at much greater distances than the Cepheid variables. We identify 49 probable Cepheids within NGC 3351 in the period range 10- 43 days which have been observed at 12 epochs with the F555W filter and 4 epochs using the F814W filter. The HST F555W and F814W data have been transformed to the Johnson V and Cousins I magnitude systems respectively. Photometry has principally been carried out using the DAOPHOT/ALLFRAME package. Reference is made to parallel measurements being made with the DoPHOT package.

Apparent period-luminosity functions for V and I have been constructed assuming values of $\mu_0 = 18.50 \pm 0.10$ magnitudes and $E(B-V) = 0.10$ magnitudes for the distance modulus and reddening of the Large Magellanic Cloud. A true distance modulus of 30.01 ± 0.19 mag is derived corresponding to a distance of 10.05 ± 0.88 Mpc with a reddening $E(V-I) = 0.15$ mag. A comparison is made with distances estimated for other galaxies in the Leo 1 group using various distance indicators. There is good agreement with the Surface Brightness Fluctuation and Planetary Nebula Luminosity Function methods as calibrated by the Cepheids in M31.

Subject headings: galaxies: individual(NGC3351) - galaxies: distances - stars: Cepheids

1. introduction

NGC 3351 (M95)($\alpha(2000)=10^h43^m58^s$; $\delta(2000) = +11°42'15"$) is a bright nearby example of a barred spiral galaxy. Sandage and Tammann (1981) classify NGC 3351 as SBb(r)II and give a B_T=10.52 mag. The de Vaucouleurs (1975) type is SB(r)b. Ground based images (see, for example, Sandage & Bedke (1994) panels 168 and 170) show a bright nucleus, broad bar and two major arms made up of stellar knots interlaced with a complex web of absorbing dust lanes. NGC 3351 contains a circumnuclear structure which is related to a twin-peaked CO distribution (Rubin, Ford, & Peterson 1975; Kenney et al. 1992). Pronounced non-circular velocities apparently result from material streaming into the nuclear region from both NE and SW and triggering star formation there. Rubin et al. adopt an inclination of 40° and a heliocentric systemic velocity of 779±3 km s^{-1}. This corresponds to a velocity of 643 km s^{-1} with respect to the local standard of rest. While the galaxy has considerable interest in its own right as an evolving stellar system, from the viewpoint of the Hubble Space Telescope (HST) Key Project, its most significant characteristic is its membership of the Leo I group which includes several other bright galaxies with morphological types ranging from elliptical (NGC 3377, 3379) and lenticular (NGC 3384) to late-type spiral and Magellanic irregular types, Several degrees to the east, we see the Leo triplet of highly inclined spiral galaxies (NGC 3623, 3627, 3628). With its reasonably open structure yet appreciable inclination, NGC 3351 was marked early as a galaxy likely to be rich in Cepheid variable stars and thus of high potential in the Distance Scale Project. We note that it is one of the earliest spiral types included in our sample.

Freedman et al. (1994a) have summarized the effectiveness of HST in detecting and measuring Cepheid variables in external galaxies. Not only the better resolution of the telescope but also the ability to optimally schedule the telescope makes it possible to carry out a survey and a study of these stars in only a couple of months rather than over the many years, even decades, whit.}~ would be needed for a ground- bad study. The ultimate aim of the HST Key Project is to provide an absolute magnitude calibration for the extragalactic distance scale. This will enable the Hubble constant to be determined to within 10% (Kennicutt, Freedman, & Mould 1995). The essence of the program is to determine Cepheid distances via the period-luminosity relation (PL relation) to 18 galaxies with redshifts out to about 1500 km s^{-1}. These in turn will provide the calibration for a number of secondary indicators such as the Tully-Fisher relation, the Planetary Nebula Luminosity Function, the Surface Brightness Fluctuation method and those criteria related to supernova brightness and expanding envelopes. As de Vaucouleurs (1975) noted, the Leo group is one of the very best for the calibration of those distance indi cators which are app licable to galaxies of a particular type.

The results for five galaxies in the Key Project program have now been published. These are M81 (Freedman et al. 1994a), M100 (Freedman et al. 1994b; Ferrarese et al. 1996); M101 (Kelson et al. 1996), NGC 925 (Silbermann et al. 1996), and NGC 3621 (Rawson et al. 1996). In a related HST project, Cepheids have been located and studied in IC 4182 (Saha et al. 1994), NGC 5253 (Saha et al. 1995) and NGC 4536 (Saha et al. 1996). First results have also been published for NGC 4639 and NGC 4496A (Sandage et al. 1996). Cepheids have been detected in the Leo 1 galaxy NGC 3368 (M96) by Tanvir et al. (1 995). As the data accumulate, our confidence in the reliability of Cepheid variables as primary distance indicators continues to grow. Mould et al. (1995) discuss the limits that ca n be placed on the Hubble constant at present.

2. observations and Data Reduction

2.1. Observations

The observing strategy is discussed in detail in previous papers of this series (e.g. Ferrarese et al. 1996) and we refer to these for more complete descriptions. Here we discuss only those issues which relate directly to this particular series concerning NGC 3351. The HST observations began on November 29 1994 using the Wide Field and Planetary Camera 2 (WFPC2). A total of 24 V images at 12 epochs, spaced over a 54 day interval, was accumulated using the F555W filter. Within this same interval 8 additional images covering 4 epochs were obtained with the F814W filter to measure *I* magnitudes. All observations were carried out at the same telescope pointing and roll angle. The positional repetition over the 54 day interval was better than 0.07 arcsec which significantly simplified the identification of stars on different frames,

The region we have observed in NGC 3351 is shown in Figure 1 which is taken from a 2048 x2048 image (V filter) obtained at the Las Campanas Observatory 2.5m du Pont telescope. The PC chip covers the smallest field. We refer to this as chip 1. The three WFC chips cover the 3 larger fields. We will refer to these as chips 2, 3 and 4 as in the 3 fields encountered anti-c. ockwise as one rotates from the PC field.

The summary of observations and exposure times is given in Table 1. The sampling strategy has been discussed by Freedman et al. (1994a). The spacing between observations was chosen to maximize the probability of detecting Cepheids with period between 3 and 60 days allowing at the same time for an optimum sampling of the light curve and reducing the likelihood of aliasing. We were fortunate that the actual observations followed very closely our requested sampling sequence. Figure 2 illustrate the probability that a variable with period P is detected given the temporal sampling on the assumption that all initial phases are equally likely (cf. Saha et al. 1994). In the calculation, the incompleteness due' to magnitude selection effects is not taken into account. This factor becomes severe for faint stars because of the large measuring errors in the magnitudes. Note in Figure 2, that with our sampling, there remains some data clumping with consequent loss of information through redundancies near periods of 10 days. Also, because of the slope of the PL relation and the incompleteness at fainter magnitudes, few Cepheid variable stars are likely to be discovered at periods less than 1(1 days.

2.2. Data Reduction

Routine calibration via the standard pipeline maintained by the Space Telescope Science Institute (STScI) has been carried out as described in previous papers of this series. All exposures were taken at the low CCD operating temperature of - 88°C so that the hot pixel problem was minimized and the "charge transfer effect" photometry gradient reduced to an insignificant amount (Holtzman et al. 1995; Hill et al. 1996). As far as possible, bad pixels are identified and flagged. The following standard team procedure for processing the fields has been formulated by Stetson and Saha.

(1) All images are retained in their 800x800 format rather than being trimmed. Vignetted regions and bad pixels are marked as follows, Using two pipeline flats, one for each F555W and 1{'814W filter, pixels that differ from the median for the chip by *less* than a factor root 2 are reset to O; pixels that differ from the median by more than root 2 have been reset to 64. The V and 1 masks are summed so that all pixels which are bad in either the V or the *I* flat are masked off in all of the data.

(2) To minimize truncation errors, images are multiplied by 4 before being converted to short integers.

(3) The science exposures are multiplied by a pixel maps which correct for geometrical distortion within the reimaging optics of WFPC2. This has to be done because individual pixels do not map onto exactly equal areas in the sky thus leading to a distortion) in the flat fields sky exposures. While frames which have been corrected by pipeline flats correctly represent the surface brightness of' astronomical objects, integrated fluxes are distorted. Multiplying; the normalized science images by a map of the projected pixel areas restores a correct flux scale to each pixel.

The first 50 rows and columns of each CCD field were blocked out due to vignetting.

3. Photometric Reduction

Photometric analysis of the data has been carried out independently by J. Graham at the Department of Terrestrial Magnetism using DAOPHOT and ALLFRAME (Stetson 1994) and by R. Phelps at the Carnegie Observatories using DoPHOT (Schechter, Mateo, & Saha 1993). As pointed out in earlier papers (e.g. Ferrarese et al. 1996), the philosophy behind the two program packages is quite different, Thus there is a useful check on the results for systematic errors which might otherwise go unnoticed if only one of the programs is used. For example, random noise events cause different responses in the two programs making them easily identifiable and clearly distinguishable from real variations in stellar brightness. The methods for determining sky background are also different.

Standard team procedures were used for the ALLFRAME measurements (see for example Silbermann et al. (1996)). As described in more detail in Hill et al. (1996), there are a few small corrections necessary to bring the photometry to the standard system used by others with the HST. We again have calculated the necessary aperture corrections to bring computed ALLFRAME magnitudes to aperture photometry with an aperture diameter of 0.5 arcsec as recommended by Holtzman et al. (1995). Since all our observations are referred to the first frame of the series, we have calculated these corrections only for that first frame. About 20-30 isolated, bright but unsaturated stars were selected from each field and aperture phometry carried out over several apertures up to and just exceeding the one corresponding to 0.5 arcsec diameter. The DAOPHOT routines DAOGROW were then used to determine an image growth curve for each chip (Stetson 1990). These growth curves were then inverted to give a predicted 0.5 arcsec magnitude for each of the stars used. This was then compared directly with the measured ALLFRAME magnitude and a correction computed. The average ALLFRAME aperture correction was then used for all other stars. The aperture corrections are shown in Table 2.

The DoPHOT photometry was performed using a variant of the DoPHOT package (Schechter et al. 1993, Saha et al. 1994) which was developed by A. Saha to deal with the photometry of undersampled images such as those obtained with the HST. The principal modification consists of an additional term, $\beta 8$, in the specification of the point spread function which modifies the wings of the PSF to compensate for the undersampled image. Additional discussion of the application of DoPHOT to photometry of HST images can be found in Ferrarese et al. (1996), Hill et al. (1996) and Saha et al. (1996).

A color correction was also applied. We used the following relations suggested by Holtzman et al. (1995) to obtain V and I magnitudes on the Johnson and Cousins systems respectively.

$$V = F555W - 0.052(V - I) + 0.027(V - I)^2$$

$$I = F814W - 0.063(V-I) + 0.025(V-I)^2$$

To good approximation, a $V-I$ of 1.0 used in these functions gives the same color correction over a range $V-I$ from 0.8 to 1.3 which will include most Cepheids. Again the color correction is small, no more than a few hundredths of a magnitude. There has been some controversy over whether or not a correction of about 0.05 mag between long and short exposure frames is appropriate (Hill et al. 1996). All of the Cepheid program frames are long exposure, but frames which have been used for calibration purposes have shorter exposures. Work by Stetson suggests that such an effect should be taken into account and we have included it in our calibration (Hill et al. 1996).

The several sequential steps in the calibration procedure leave open the possibility of cumulative error. Thus, we think it wise to make available for each chip a set of measurements of bright unsaturated stars which can be remeasured easily at a later date. The stars used in the growth curves are very suitable for this purpose and we include in Table 3 positions and ALLFRAME magnitudes for several of these for each chip.

The independent data reductions using ALLFRAME and DoPHOT provide a good external test for the accuracy of the PSF fitting in these crowded and complicated fields. A detailed discussion and comparison of these programs will be presented in a future paper (Stetson et al. in preparation). Here we summarize the results of our comparisons for NGC 3351. We first compared the photometry for the relatively isolated bright stars on each chip listed in Table 3. We then performed the same comparison for the Cepheids in our final sample. In both cases the overall agreement is reasonable. The mean differences for each chip along with the internal standard errors for these means are listed in Table 4. Some large individual differences remain and we have excluded in the computation differences greater than twice the standard deviation per star. We are continuing to explore the nature of the isolated discrepancies and we shall present a more complete discussion in Stetson et al. (in preparation).

Since 110 serious discrepancies are found, for simplicity and consistency with other papers of this series, we are presenting the results of only one of the two sets of photometric data, that from ALLFRAME. The ALLFRAME photometry for each star is listed in Table 5 along with the mean Julian Date of the observation and an estimated 1σ error based on the psf fitting. We believe these anticipated errors are conservative and mostly arise from fitting a psf to undersampled images for which most of the counts are confined to a single pixel. As will be seen from the light curves, epoch to epoch variations indicate that, for bright stars, the reported errors may be overestimated by a factor of about two. Since two cosmic ray-split exposures are obtained at each epoch and the photometric reduction is done independently on each of them, we have averaged the two magnitudes measured at each epoch unless the reported magnitude error was greater than three times the standard deviation. In such a case, only the more precise value of the pair was used.

4. Variable Star Search

4.1. (a) DAOPHOT/ALLFRAME Data Set

Two methods have been used by JAG to search the DAOPHOT/ALLFRAME data set. They complement each other by emphasizing in turn the tasks of detecting variability and searching for periodicity. The first is a version of the Welch - Stetson correlated residuals procedure which has been adapted for the project by N. Silbermann. The method is described by Welch & Stetson (1993). It depends on the simple concept that, while photometric measuring errors have a random distribution with time, residuals due to intrinsic variability are likely to be strongly correlated. The method works especially well with the 11 ST data sets in which observations are paired for random event (cosmic ray) removal. A variability index is computed for each of the stars measured by ALLFRAME. A filter is incorporated into the program to remove the large differences which may be introduced by isolated erroneous magnitudes. This also serves to remove epochs for which ALLFRAME finds itself unable to measure a sensible magnitude and outputs instead an unrealistically large one. A lower limit on the index needs to be specified in order to limit the suspect list to those stars which have some chance of being variable. The resulting list is then sorted in decreasing value of the index. The true variable stars can usually be found at the top of this list. occasionally, a bad pixel measurement will produce a single epoch magnitude which will distort the index and give an erroneous detection. Such cases are easily spotted by inspection.

Another powerful method of Cepheid detection is to attempt to fit a period for the sequence of measured magnitudes. For this we have used a version of the Lafler-Kinman (1965) technique as formulated by Stellingwerf (1978). Our version was adapted for the project by S, Hughes. On being given a period range to search, the "phase dispersion minimum" program takes the data set, and with a trial period computes phases. The magnitude list is reordered in order of phase and a difference sum of the adjacent brightness measurements is calculated. For a random series of magnitudes, this difference remains large, regardless of changes in the input period. When there is a real periodic variation and the correct period is approached through the successive trials, the sum becomes small. The program computes the difference sum for a succession of trial periods whose spacing depends on the time base of the data set and outputs the periods for which it is at a minimum, along with graphical displays of the difference sum vs period, magnitude vs epoch and magnitude vs phase for those periods. The method is particularly effective at finding periods between 0.25 and 1.0 times the time base of the observations. For shorter periods, it, tends to get confused by the photometric residuals and will compute spurious periods. Experience shows that the phase dispersion minimum method is more sensitive to large residuals in the photometry (e.g. from random events on the chip) than the correlated residuals method.

4.2. (b) DoPHOT Data Set

The search for variable stars with the DoPHOT data set was performed using each of the 24 F555W(V) images in a manner somewhat different from the technique outlined by Ferrarese et al. (1996). A frame was created by co-adding 16 of the individual frames and applying the "pclip" cosmic ray rejection algorithm within IRAF. A master list of objects was then obtained by performing a DoPHOT run on the master frame. The master list with coordinates transformed to each of the appropriate individual frame coordinate systems was then used as the input list for DoPHOT photometry runs on each frame. The end result was a set of 24 photometry files for the 12 epochs, with each epoch having two cosmic ray split frames. Calibration of the DoPHOT output magnitudes is discussed in Hill et al. (1996).

The detection of variable stars is accomplished by an automated routine which is essentially identical to that described in Saha and Hoessel (1990a). A star is flagged as a candidate variable based on a χ^2 test of the deviation, weighted by the photometric uncertainty, of a star's magnitude over a specified number of epochs. After the star is flagged as a candidate variable, a periodicity test is performed using again the Lafler-Kinman (1965) algorithm. Using a range of test periods, minima in the spectrum of the difference sum statistic are used to determine possible true periods. A period refinement, using software developed by A. Saha, is then made by interactively investigating other less likely periods that result from different distance sum minima. In this way, one can exclude periods which may result from spurious points such as might occur as a result of cosmic ray events or from aliases.

4.3. (c) Search Results

Our endeavor is to obtain as sample of Cepheid variable stars with properties similar to those known in the Galaxy and the Magellanic Clouds. Thus the prime criterion for accepting a star as such in NGC 3351 is the appearance of the light curve relating magnitude to phase-wrapped epoch. Quantitative parameters, such as those based on correlated residuals or phase dispersion minima are invaluable for discovery but quantitatively are susceptible to random events and photometric errors. They are not helpful in distinguishing long period variables, eclipsing stars and novae, for example, from Cepheids. More sophisticated routines for doing just this are currently being tested at the Dominion Astrophysical observatory by P. Stetson. Typical Cepheid light curves are well-known from the LMC sample (e.g. Wayman, Stifft, & Butler 1984). They are sometimes sinusoidal but more often show a rise in brightness more rapid than the decline. In some senses, discrimination by light curve-shape parameters alone is a more quantitative procedure but decisions about the critical values used for the parameters are themselves based on personal experience. Thus the decision process is only moved back one step. Inclusion of Cepheid . variables pulsating in the first overtone (Böhm-Vitense 1990) is minimized by avoiding stars with periods less than 10 days. While Population II W Virginis stars might be expected in a spiral galaxy with a type as early as that of NGC 3351,' reference to published PL relations (Nemec & Lutz 1993) shows that even the longest period examples of these stars would be much fainter than our detection limit.

After engaging in separate searches, we compared candidate lists and examined in detail those stars flagged in only one search. We found this double search profitable. Most variables (46) indeed were found independently in both data Sets. In 3 cases with only a single discovery, the explanation lay in the different treatment of random events by the two different procedures. A more thorough analysis of the effect of samples found separately by ALLFRAME and DoPHOT is given by Ferrarese et al. (1 996). 'l'here it is shown that the resulting distance moduli arc not sensitive to small changes in the selection criteria for variables or the source of the sample. our aim is to produce a single list of Iligl]-weight Cepheid variables, free of bias, using the two photometric data sets.

Our final list of variables is given in 'J'able 6. Coordinates based in WFPC2 measurements and the stated position of the telescope are given. Notes arc given at the foot of Table 6 following a visual inspection of the stars 011 the combined frames. Finding charts arc provided in Figures 3, 4, and 5 . Wc do not expect our list to be complete at periods around 10 days or less. A histogram of the period distribution (normalized to an integrated total of 50) is shown as Figure 6 and is compared with the Magellanic Cloud calibrating sample (Madore 1985) (dashed lines) and the Cepheid variables known in Fields II, II, and IV of M31 (Baade & Swope 1963,1965)(dotted lines). The agreement is unexpectedly good even at snort periods but there may be a deficiency at longer periods. our data set, with a time base of 54 days only allows inclusion of periodic variables with periods shorter than this interval. It is possible that a few additions may be made following analysis of new data following the HST revisit to NGC 3351 made in December 1995 but it is clear that the crowding and high background must limit our ability to detect variable stars over the whole period range in these fields.

5. Light Curves and Mean Magnitudes

The light curves, phased to the periods in '1'able 6, are reproduced in Figure 7. They arc arranged in order of decreasing period and are lined up so that phase = 1.0 corresponds to maximum brightness. They are folded over two cycles to assist in the study of their morphology. The adopted period is shown in each panel. A characteristic error reported by ALLFRAME for the magnitudes in each set is shown in the lower left corner of each panel, As mentioned earlier, these error bars may be overly conservative for the brighter stars. A perusal of the panels in Figure 7 confirms that they are typical of curves expected from normal Cepheid variable stars with the rise to maximum being; faster than the decline to minimum. Star c09 has an unusually low amplitude and a flat-bottomed light curve. This immediately suggests the presence of a companion star and inspection of the frames indeed shows a bright blue star which must be contaminating the photometry. We will thus exclude c09 from the PL fits.

Mean V and I magnitudes are routinely computed in two different ways; as intensity averaged magnitudes $< V >_i$, $< I >_i$ and as phase weighted magnitudes $< V >_{ph}$, $< I >_{ph}$ (see Saha & Hoessel 1990b). For variable stars with uniformly sampled light curves, these coincide but whenever the phase coverage of the light curve is not uniform, higher weighting of the less common phase points provides a more accurate estimate of the mean magnitude than a simple intensity average. Both are listed in Table 7 for each Cepheid variable star along with the period and log period. Since only 4 epochs have been observed in the I band, the poor phase coverage makes both the intensity averaged magnitude and the phase weighted magnitude representations of the mean I magnitude which are sometimes inaccurate. Advantage can be taken of our better sampling of the form of the V light variation. Freedman (1988) has found that there is a good correspondence between the V and I light curves in that, at least as a first approximation, one can be mapped onto the other by simple scaling. The ratio of V to I amplitude is found to be 1:0.51. Thus we can derive an additional correction to the mean I magnitude by first calculating the difference between the mean V magnitude from the complete V data set and then a mean using only those V data points in common with the I observations and then by scaling this difference with the 1:0.51 ratio. The result is then added as a correction to the phase weighted I

magnitude. This I magnitude, $<I>_{\Delta I}$, which we consider as the best estimate with our limited data, is also listed in Table 7. By comparing the columns in Table 7, it can be seen that the differences between the columns, are generally small. The average numerical difference is 0.06 mag while the mean difference $<I>_{\Delta I} - <I>_{ph}$ is + 0.014 0.01 showing that no significant systematic error is introduced by this procedure.

An I, $V-I$ color magnitude diagram for all stars is shown as Figure 8. Cepheids are marked as filled circles, other stars as points. With two exceptions, the Cepheids lie in a band bounded by $V-I$ = 0.5 and 1.5 mag. The blue star c46 is very faint, one of the two faintest in the Cepheid sample. The light curve, shown in Figure 7, looks normal. The abnormality is in the very faint I magnitude which may be inac.curate because of the high background. Visual inspection snows that c17 has a very red companion star which must be affecting the photometry. These two outliers are also dropped from the PL relations derived in the next, section. While the Cepheids define an instability strip, the points representing the field stars do not snow the same amount of segregation into different populations as in other papers of this series. It is possible that this is due to an unusually large amount of differential reddening by dust in this galaxy or to a relatively complex star formation and chemical history. But we also note that some of these fields are much more crowded than those we studied in NGC 925 and NGC 2090, for example, and that the fuzzy appearance of the red giant branch may just be due to photometric errors.

6. Period-Luminosity Relations and the Distance to NGC 3351

Following other papers in this series (Freedman et al. 1994a 1994b; Kelson et al. 1996; Ferrarese et al. 1996; Silbermann et al. 1996), the apparent V and I distance moduli to NGC 3351 based on the DAOPHOT/ALLFRAME data set are derived using a standard application of the published V and I PL relations listed by Madore and Freedman (1991).

These depend on LMC Cepheid data scaled to a true modulus of 18.53 0,10 mag corrected for an average line of sight $E(B-V)$ reddening of 0.10 mag ($E(V-I) = 0.13$ mag). They are:

$$M_V = -2.76 \log P - 1.40$$

$$M_I = -3.06 \log P - 1.81$$

To avoid bias in fitting the slope due to incompleteness at short periods, we continue previous practice by fixing the slope to the Madore and Freedman (1991) values quoted above. Phase weighted magnitudes are used. With the first pass of all the data in Table 7, there were 3 outlying points which correspond to stars c07,c17,c46. Stars c17 and c46 were commented upon in the previous section. The star c07 has a very high background and a poor light curve. Thus there is good reason to eliminate these stars and c09, also discussed in section 5. The V and I period luminosity plots are shown in Figures 9 and 10 with the fits superposed. The solid lines represent the best unweighted fit. The dashed lines, drawn at ± 0.54 mag in Figure 9 and at ± 0.36 mag in Figure 10 reflect the finite width of the Cepheid instability strip and thus the expected 2σ scatter around the best fitting PL relation. The functional relations are:

$$\langle V \rangle = -2.76 \log P + 28.98$$

$$\langle I \rangle = -3.06 \log P + 28.42$$

These lead to V and I moduli of 30.38 ± 0.06 and 30.23 ± 0.05 mag respectively with $E(V-I) = 0.15 \pm 0.03$ mag for the NGC 3351 Cepheids. Using the procedures described in the papers cited above, the apparent moduli are related through the Cardelli et al. (1989) extinction law of $A_B{:}A_V{:}A_I$ = 3.3:1.0:0.6 and used to derive a true modulus of 30.01 ± 0.07 mag. The quoted error is based strictly and formally on the observed σ about the mean as reduced by the square root of the number of remaining degrees of freedom. We have made an error budget for our determination. This is shown in Table 8. Note that one of the largest uncertainties still remaining is the true modulus of the Large Magellanic Cloud. Figure 11 demonstrates the anticipated correlation of the residuals from the V and I PL relations for the Cepheids in NGC 3351. The solid line shows the expected slope and full width of the anticipated correlation of data points if due to intrinsic strip-width (temperature) effects. Most of the stars lie within this boundary. Most of the stars lie within this boundary. The dotted line shows the reddening trajectory. Three stars on the upper right which appear to have unusually high reddening are among the 4 which lie below the instability strip in the PL plots. Incorporating all uncertainties, we find a standard "' error of 0.19 mag for the true modulus of 30.01 mag for NGC 3351. This corresponds to a distance of 10.05 ± 0.88 Mpc. Analysis of the DoPHOT data set gives a similar result. Using the same procedures, the DoPHOT photometry gives apparent V and I moduli of 30.42 and 30.26 mag with $E(V-I) = 0.16$ mag and a true modulus of 29.98 for NGC 3351.

Following a suggestion from the referee, we have looked into the possibility of magnitude bias caused by the lack of fainter stars at a given period. We carried out our analysis by starting with the brightest Cepheids and and calculating apparent and true moduli as we increased the sample moving to fainter magnitudes. We found that there is indeed a systematic trend for the apparent moduli to increase as we moved fainter (contrary to what one would expect for a magnitude cut-off effect). But it is small and amounts cumulatively to approximately 0.1 mag. On the other hand, the true modulus calculated for these same samples Varies a lot less systematically and is clearly no more than 0.05-0.07 mag. We conclude that if this effect was taken into account it would make the final true modulus smaller by that amount. The effect is not a major one and is uncertain with the number of stars involved and we have refrained from making a correction to our final result on this account.

7. The Leo I Group and the Calibration of Secondary Indicators

The sheer diversity of its member galaxies makes the Leo I group an important Last for calibrating secondary distance indicators, provided that its own distance can be anchored by a tried and proven method. We could attempt this with our new distance of 10.0 Mpc based on this sample of 45 Cepheid variables in NGC 3351, but we prefer to postpone the calibration until more data from other groups of galaxies observed in the Key Project become available. Kennicutt, Freedman, & Mould (1995) and Jacoby et al. (1992) reviewed the various secondary distance indicators and provided assessments of their potential along with useful bibliographies. It is remarkable, as one reads through their lists how many such indicators are featured in one or other galaxy of the Leo I group and it is useful to survey what is already known about them here.

Most of the Leo I galaxies are in a compact 3°X 1,5° core which includes both NGC 3351 and a second bright spiral NGC 3368(M96). Others are NGC 3377, NGC 3379(M105), NGC 3384 and NGC 3412. Surrounding NGC 3379 is a large intergalactic ring of H I (Schneider 1985,1989) which may be interacting with NGC 3368. The elliptical galaxy NGC 3377, with its system of globular clusters has a faint dwarf companion galaxy DDO

88. Schneider (1 989) discovered a second, extremely faint dwarf galaxy which is also apparently part of the group. Eight degrees away, at a transverse distance of the order of 1.5 Mpc, is the Leo 1 triplet NGC 3627(M66), NGC 3623(M65) and NGC 3628 which are mutually involved in a tidal encounter (Burkhead & Hutter 1981). A combined census of 50 galaxies is included in group 56 of Huchra & Geller (1 982). Some of these have questionable membership (Schneider 1 W). We point out that another group in this part of the sky, known as the Leo 11 group, is made up of galaxies which are much more remote,

(a) Cepheid Variables in NGC 3368(M96)

Cepheids have been studied with HST in one other galaxy in the Leo I group, NGC 3368(M96). A summary of the results has been published by Tanvir et al. (1995). They found a distance of 11.640.8 Mpc corresponding to a true modulus of 30.32 mag based on observations of 7 Cepheids. They obtained observations at 13 epochs in V over a period of 7 months. 1$01'3 of these epochs, I magnitudes were also measured. Intensity means only were plotted and used in determining the PL relations. It is instructive to compare their results with ours as the two galaxies are c. 1osc in the sky, separated by 41 arcmin which corresponds to a transverse distance of 120 Kpc at 10 Mpc. Allowing for measuring errors, their 1'1, relation in V seems to agree. with the one we derived with our larger Cepheid sample. It is the 1'1, relation in I which is approximately 0.2 mag fainter and leads to an absorption correction less and, in turn, to a true modulus correspondingly greater than our values. While this is arithmetically responsible for the larger distance that they give, it may not be surprising as their field is sparser and further out in the disk than ours in NGC 3351. It is conceivable also, as Tanvir et al. point out, that there is a significant extension of the group along the line of sight in this direction but, if so large, it must be much greater than the transverse separation.

(b) The Infrared Tully-Fisher Relation (IRTF)

There are several galaxies in the Leo I group, including the two with known Cepheids, which are suitable for the calibration of the IRTF relation. The neighboring Leo triplet NGC 3623, NGC 3627, NGC 3628 was included among the groups studied by Aaronson & Mould (1 983). Using an earlier calibration based on M31 and M33, they obtained a distance modulus of 29..$34 mag with an observational uncertainty of 0.25 mag which is broadly consistent with our value for NGC 3351. We note that, while a new distance to the Leo triplet would add these three new IRTF calibrators to those considered by Freedman et al. (1 W), this distance is not necessarily the same as the distance to the Leo 1 group that we find in this paper.

(c) D_n - σ Relation

This, a dynamical analog of the Tully-Fisher relation, is applied to large elliptical galaxies or spiral bulges. As Jacoby et al. (1992) point out, the method has mostly been applied to measure relative distances since there are no nearby examples of large elliptical galaxies which can be used for the calibration, Faber et al. (1 989) have included data for two of the elliptical galaxies in the Leo 1 group, NGC 3377 and NGC 3379. Their distance R = 857 ± 126 km s^{-1} and a Hubble constant of 80 ± 17 km s^{-1} Mpc^{-1} yields a distance of 10.7 ± 2.7 Mpc which is consistent with our measurement for NGC 3351.

(d) Surface Brightness Fluctuations (SBF)

This quantitative criterion of the resolution of a galaxy into its individual stars has been developed by Tonry (1 991) and his collaborators. Five Leo I galaxies NGC 3368, NGC 3377, NGC 3379, NGC 3384, and NGC 3412 have now been observed (Tonry et al. 199(i). A new calibration of the SBF methods yields a modulus for Leo 1 of 30.14 mag ± 0.06 which agrees, within observational uncertainties, with our value for NGC 3351.

(c) Planetary Nebula Luminosity Function (PNLF)

The P NLF up until now has been mainly applied to ellipt ical galaxies and galaxies with bulges. With a calibration based on the planetary nebula luminosity function in M31 , Ciardullo et al. (1989) find distances of 9.8, 10.6, 10.1 and 10.4 Mpc for NGC 3368, NGC 3377, NGC 3379 ant] NGC 3384 respectively with an uncertainty of about 0.7 in each value. 111 a very recent paper, Feldmeir, Ciardullo, & Jacoby (1 996) confirm that the method can be extended to later-ty})c galaxies and determine a new distance of 9.6 Mpc ± 0.7 for NGC 3368(M96). The general agreement with our distance to NGC 3351 suggests that 110 large revisions are likel y to be required for this calibration.

(f) Expanding Photosphere Method for Type 11 Supernovae (EPM)

This is a refinement of the Baade-Wesselink method as applied to the expanding envelopes of Type I I supernovae. Descriptions of the method can be found in Schmidt et al. (1 994) and references therein. One of the main advantages of the method is the large range of distances over which it can be applied. SN1973R was in NGC 3627. The EPM distance, 15.0 ± 7.0 is not well determined owing to the uncertainty of the date of maximum (Schmidt, private communication) but it is broadly consistent with the NGC 3351 value. We are hopeful of more Type 11 supernovae in order to Letter assess the importance of this promising distance indicator.

(g) Peak Luminosities of Type Ia Supernovae

The relatively low dispersion of this distance criterion and its large potential range are very attractive. However, no type Ia supernovae have been recognized in the Leo 1 group itself. SN1989B in the Leo triplet galaxy NGC 3627 is included in the sample of well observed type] a supernovae discussed by Phillips ( ] 993). It was observed intensively at the time of outburst and very good spectroscopic and photometric data are available (Wells *et al.* 1994). SN1989B has almost the same decline rate as SN1980N which occurred ill NGC 1 316 of the Fornax cluster. Mark Phillips (private communication) has pointed out that the strong li nk from Leo I to the Fornax c lust er via the SBF and PNLF methods along with the relative brightnesses of the two supernovae suggests that the Leo triplet has a modulus smaller, by about 0.5 mag, than the Leo I group. NGC 3627 is on the existing SN Ia program with HST and we thus expect a more direct calibration later.

(h) Globular Cluster Luminosity Function (GCLF)

This method also has a large potential range and is described by Harris et al. 1991. It is uncertain yet whether we will include this parameter for calibration) in the Key Project but in the present context, we point out that Harris (IWO) has discussed available observations for NGC 3377 and NGC 3379. Using a combined GCLF for these galaxies and comparing it with that of the Milky Way globulars, he finds a true modulus of 30.14 ± 0.43 mag or a distance of 10.7 ± 2.2 for the Leo I group (A foreground absorption A_B = 0.05 mag is assumed). Comparing the GCLF of the Leo I group galaxies with that of the Virgo cluster galaxies, he finds a differential modulus of 1.42:1 0.41 mag. Using our M100 Cepheid modulus, 31.043 0.21 mag (Ferrarese et al. 1996), this translates to a modulus for Leo 1 of 29.59 ± 0.46 (errors added in quadrature) again consistent with our determination for NGC 3351.

We have surveyed the various secondary indicators again here to emphasize that our study of the Cepheids in NGC3351 within the Leo I group is very much a small scale preview of what we plan to achieve in the Key Project as a w11olc, The Key Project is essentially a calibration task to tie down these secondary indicators sufficiently firmly that our ultimate aim of determining a global H_0 to within 10% can become a reality. While in the course of our work, we are able to set limits on H_0 (e.g. Mould et al. 1995), the final definitive values will not come until after this task is completed.

The work presented in this paper is based on observations with the NASA/ESA Hubble Space Telescope, obtained by the Space Telescope Science Institute, which is operated by

AlJ]{A, Inc. under NASA contract No. 5-26555. We gratefully acknowledge the help of the NASA and S']%] support staff, with special thanks to our program coordinator, Doug Van Orsow. Support for this work was provided by NASA through grant GO-2227-87A from STScI. Jon Holtzman provided the pixel maps that we used to correct our frames for geometrical distortion. Robin Ciardullo, George Jacoby, Mark Phillips and John Tonry provided valuable comments and communicated some data prior to its publication.
comments and communicated some data prior to its publication.
JAG would like to acknowledge with gratitude the generous help and advice from Sandy Keiser in getting the reduction software into operation.

'J'able]. Log of Observations

Ohs. Datc	JD (mid-exp)	Exposurc Time (sCc)	Fi1tcr
29/1 1 /94	2449686.349	1500	F555W
29/1 1 /94	2449686.402	1000	F555W
29/11/94	2449686.418	1200	1"814W
29/1 1 /94	2449686.470	1200	F814W
07/1 2/94	2449694,462	1500	F555W
08/12/94	2449694.562	1000	F555W
16/12/94	2449703.442	1500	F555W
16/12/94	2449703.500	1000	F555W
19/12/94	2449705.789	1500	F555W
19/12/94	2449705.832	1000	F555W
19/12/94	2449705.856	1100	I"(SI4W
19/1 2/94	2449705,910	1000	1"814W
22/12/94	2449708.537	1500	F555W
22/12/94	2449708.596	1000	F555W
24/12/94	2449711.285	1500	F555W
24/12/94	2449711.338	1000	F555W
28/12/94	2449714.905	1500	F555W
28/1 2/94	2449714.958	1000	F555W
01/01/95	2449718.591	1500	F555W
01/01/95	2449718.644	1000	F555W
01/01/95	2449718.658	1 000	F814W
01/01/95	2449718.711	1500	F814W
05/01/95	'2449723.07$	1500"	F555W

'1'able 1- Continued

Obs. Date	JD (mid-exp)	Exposure Time (sec)	Filter
05/01 /95	2449723.135	1000	F555W
1 0/01 /95	2?449728.108	1500	F555W
10/01/95	2449728.162	1000	F555W
16/01/95	2449734.072	1400	F555W
16/01/95	2449734.126	1000	F555W
16/01/95	2449734.141	1100	1"814W
16/01/95	2449734.196	1400	F814W
23/01/95	2449741.303	1500	F555W
23/0]/95	2449741.366	1000	F555W

Table 2. Apertu e Corrections

Chip	Correction	p.e.
	(a) F555W (V)	
1	-0.11	0.03
2	-10.01	0.02
3	-10.01	0.01
4	-0.03	0.01
	(b) F814W (I)	
1	-0.08	0.02
2	-0.10	0.03
3	-0.09	0.02
4	- 0.02	0.03

Table 3. Magnitudes of Bright Stars

Star	x	y	R, A.(2000) h m s	Dec.(2000) ° ′ ″	V (mag)	I (mag)
1-1	54'7.97	88.07	10 43 51.60	11 41 18.91	24,51	24.68
1-2	557.27	273.30	10 43 51.35	11 41 26.39	24.83	24.95
1-3	520.86	313.31	10 43 51.40	11 41 28.71	24.44	24.27
1-4	442.18	353.84	10 43 51.57	11 41 31.80	24.00	23.84
1-5	160.42	524.22	10 43 52.16	11 41 43.91	25.01	25.15
1-6	164.35	731.32	IO 43 51.90	11 41 52.37	23.39	23.35
1-7	383.79	736.19	10 43 51.27	11 41 48.69	24.26	23.91
2-1	534.78	123.05	10 43 52.35	11 42 14.12	21,49	21.05
2-2	235.86	160.35	10 43 53.39	11 41 48.56	24.05	22.63
2-3	465.27	372.67	10 43 54.08	11 42 17.80	22.15	21.48
2-4	404.84	483.77	10 43 54.93	11 42 16.76	22.80	21.76
2-5	720.38	514.69	10 43 54.26	11 42 46.47	21,35	21.32
2-6	332.97	645.04	10 43 56.11	11 42 16.69	22.98	20,34
3-1	227.28	135.08	10 43 54.51	11 41 26.03	22.26	21.74
3-2	256.38	241.66	10 43 54.97	11 41 17.53	21.64	20.85
3-3	90.05	265.90	10 43 54.02	11 41 08.78	23.47	23.46
3-4	489.34	297.90	10 43 56.56	11 41 21.62	23.64	22.36
3-5	179.65	535.92	10 43 55.29	11 40 47.83	23.77	23.33
3-6	656.59	674.71	10 43 58.60	11 40 54.06	23.97	'23.61
4-1	559.33	131.17	10 43 53.89	11 40 36.27	23.53	23.46

Table 3 Continued

Star	x	Y	R.A.(2000) l l l l l s	Dec.(2000) ° ' "	V (mag)	1 (mag)
4-2	168.08	159.20	10 43 52.70	11 41 10.80	22.70	21.64
4-3	507.92	220.24	10 43 53.21	11 49 37.52	23.38	22.50
4-4	647.88	313.96	10 43 53.00	11 40 21,17	23.83	22.68
4-5	512.21	649.63	10 43 50.56	11 40 20.61	24.48	23.88
4-6	420.15	709.22	10 43 49.95	11 40 26.70	22.30	22.25

Table 4. D AOPH OT/ALLFRAME minus DoP HOT Photometry

Chip	No. Stars	'A-V	No. Stars	'A 1
		(a) Bright Stars		
1	7	-0.15 ± 0.03	7	-10.05 ± 0.02
2	6	-0.064 0.07	6	-0.074.0.07
3	7	+ 0.033 0.03	7	–0.04 3.0.03
4	6	-0.034 0.04	6	-0.104 0.02
		(b) Cepheids		
1	5	- 0.04 ± 0.05	5	+ 0.07 ± 0.08
2	12	+ 0.064 0.07	9	-0.0240.09
3	16	0.004 0.03	15	- 0.01± 0.03
4	13	+ 0.07:1 0.03	12	-10.01 ± 0.03

Table 5a. V Photometry for the Final Sample

JD	c01 P=43.0	c02 P= 41.0	c03 P= 37.9	c04 P= 36.8	c05 P=35.0
2449000 .-i	$V \pm$ AV	$V \pm \Delta V$	$V \pm \Delta V$	V ± AV	$V \pm \Delta V$
686.375	24,7640.14	24.1 1±0.07	25.37±0.10	24.3840.09	24.7840.13
694.492	24.53±0.12	24.6840.08	24.49± 0.10	24.7040.11	24.7430.12
703.471	24.1530,08	24.86± 0.05	24.7640.11	24.8340.12	25.28± 0.13
705.815	24.22±0.08	24.91± 0.07	24.7530.08	24.62±0.10	25.14±0.12
708.567	24.203.0.10	24.80± 0.07	24.9240.10	24.10:10.09	25.32±0.18
711.311	24.31±0.08	24.6340.07	25.1040.10	23.91 ±0.06	25.32±0.19
714.931	24.36±0.09	24.12± 0.04	25.18±0.12	24.06±0.08	25.4140.16
718.617	24.53±0.10	23.9740.05	25.37:10.12	24.1340.12	24.9240.13
723.106	24.5740,10	24.09:10.06	25.5340.14	24.3440.14	24.49±0.24
728.135	24.65±0.11	24.2540.05	25.3040.14	24.4730.07	24.64± 0.10
734.099	24.8540.13	24.4530.07	24.4{)4 0.11	24.6740.09	25.12±0.15
741.333	24.1640.08	24.65:10.06	24.7630.11	24.8210.10	25.3640.57

'1'able 5a. V Photometry for the Final Sample

JD	c06 P=34.5	C07 P=34.5	c08 P=32.0	c09 P=32.0	c10 P= 27.0
2449000.+	$V \pm \Delta V$	$V \pm \Delta V$	$V \pm \Delta V$	$V \pm \Delta V$	$V \pm \Delta V$
686.375	24.85±0.08	26.2140.23	24.69±0.21	24.10±0.24	26.54 S0.32
694.492	24.89±0.15	25.59±0.31	25.024-0.27	24.00±0.10	26.47±0.45
703.471	24.4940.12	26.0940.30	24,0040.15	24.0640.09	26.2230.30
705.815	24.0640.08	26.0640.21	24.2130.14	23.9840.09	25.88±0.18
708.567	24.233.0.08	26.12±0.22	24.22± 0.18	23.92±0.11	25.96±0.17
711.311	24.39±0.05	26,0030.26	24.364.0.23	23.70±0.10	26.024-0.20
714.931	24.61±0.11	26.324-0,40	24.51±0.16	23.86±0.10	26.11±0.25
718.617	24.77±0.11	26.0640.25	24.794.0.21	23.9430.09	26.52± 0.32 ,
723.106	25.08±0.15	25.77±0.23	24.8740.20	24.03± 0,11	26.62±0.34
728.135	25.15±0.10	25.71±0.21	24.8240.20	24.11:10.09	26.124.0.35
734.099	25.0630.12	25.59±0.23	24.0820.13	24.11 ±0.09	25.7520.20
741.333	24.03±0.13	25.7940.23	24.344.0.70	23.8040.08	26.35±0.35

'l'able 5a. V Photometry for the Final Sample

JD 2449000.+	C]1 P=25.7 V ± AV	c12 P=24.7 V ± AV	c13 P=24.4 V ± AV	c14 P=23.9 V ± AV	c15 P=23.4 V ± AV
686.375	24.91±0.15	25,5230.07	24.77:10,11	26.363-0.21	25,2630.18
694.492	25.29±0.12	25.73±0.17	25.263,0.10	25.28±0.10	24.46±0.12
703.471	25.40±0.16	24.88± 0.08	25.493.0.17	26.19±0.16	24.76±0.12
705.815	24.34±0.07	24.97±0.10	25,3540.14	25.77±0.12	24.9430.16
708.567	24.533-0,09	25.463.0.10	24.49±0.10	25.93±0.12	25.21±0.13
711.311	24.74±0.09	25.36±0.16	24.7140.11	26.05±0.13	25.13±0.18
714.931	24.97±0.24	25.89±0.16	24.7630.15	26.2330.19	25.044-0.15
718.617	25.3430.14	25.903.0,11	25.03±0.14	25.05±0.10	24.28± 0.12
723,106	25.724-0.14	25.5840.15	25.4130,12	25.5630.12	24,514.0.14
728.135	25.57±0.16	25.003-0.09	25.56±0.13	25.57±0.11	24.944:0.11
734.099	24.5040,08	25.4530.08	24.5530.17	25.9440.14	25.07±0.16
74].333	25.2540.18	25.974-0.19	24.9540.10	26.03±0.16	24.4740.10

Table 5a. *V* Photometry for the Final Sample

JD 2449000,+-	c16 P=21.6 V ± AV	c17 P=21.4 $V \pm \Delta V$	c18 P=20.8 V ± AV	c19 P=19.8 V ± AV	C20 P=19.5 V ± AV
686.3'75	26.243-0.14	26.613-0.21	25.8440.15	25.26±0.18	...
694.492	25,6540.14	26.66 s-0.20	26.6930,15	25.284.0.13	26,0840.15
703.471	25.573-0.09	26.3830.16	26.6030.19	25.543-0.15	25.313-0.15
705,815	25.71±0.10	26.47±0.18	26.344-0.13	25.43±0.14	25.603,0.16
708,567	26.02±0.13	26.87±0.22	25.804-0.15	24.71±0.10	25.77±0.19
711.311	26.32±0.15	26.82±0.13	26.1340.14	25.024-0.09	25.824-0.12
714.931	26.1130.19	26.7240.15	26.393-0.17	25.43±0.08	25.883,0.11
718.617	25.374-0.14	26.66±0.24	26.924-0.2]	25.57±0.12	24.74±0.11 ...
723.106	25.83±0.17	26.46±0.16	26.953.0.41	26.16±0.13	25.363-0.10
728.135	26.08± 0.19	26.51:10.24	25.80±0.11	24.5640.09	25.8040.09
734.099	25.9540.21	26.9540.24	26.3840.15	25.3940.13	25.8840.12
741.333	25.353.0.12	26.62±0.17	27.0240.32	25.84±0.16	25.114.0.07

Table 5a. V Photometry for the Final Sample

JD 2449000.+	c21 P=19.0 $V \pm \Delta V$	C22 P=17.5 $V \pm \Delta V$	c23 P=16.9 $V \pm \Delta V$	c24 P=16.1 $V \pm \Delta V$	c25 P= 16.1 $V \pm \Delta V$
686.375	25.8040.28	25,223.0.15	26.29±0.24	25.84$0.22	25.4230.18
694.492	25.66±0.12	25.9540.20	26.33±0.31	25.553-0,16	26,113-0.24
703.471	25.52±0.16	24.9640.16	26.47±0.30	25.80±0.16	25.65±0.17
705.815	25.79±0.22	25.10:10.14	26.92±0.26	26.1930.16	25.8440.19
708.567	25.893.0.24	25.88±0.22	27.44±0.58	26.363-0.13	26.33±0.23
711.311	25.42±0.12	25.654-0.14	26.33±0.16	25.02±0.07	26.42:10.15
714.931	24.99±0.16	26.123-0.21	25.88±0.54	25.34±0.10	25.37±0.42
718.617	25.31± 0.09	24.8340.15	26.86±0.26	25.874.0.16	25.41±0.14
723.106	25.66±0.19	25.1720.15	26.92±0.37	26.15 ±0.17	26.0930.19
728.135	25.7640.18	25.5640.20	26.52±0.25	25.1040.08	26.06±0.16
734.099	25.0140.10	25.64± 0.25	26.02±0.20	25.7440.14	25.25:10.13
741.333	25.53±0.20	25.6430.12	···	26,854.0.23	26.11±0.18

Table 5a. V Photometry for the Final Sample

JD 2449000.-i	c26 P=16.0 V ± AV	c27 P=15.8 $V \pm \Delta V$	c28 P=15.4 $V \pm \Delta V$	c29 P=15.2 $V \pm \Delta V$	c30 P=15.2 V ± AV
686.375	25,61 ±0.22	26.14± 0.30	25.1430,14	25.224.0.09	25.50±0.20
694.492	25.10±0.14	25.23±0.12	25.62± 0.1 1	25.133-0.17	24.89±0.12
703.471	25.5840.17	25.943-0.23	25.0340.12	24.72±0.09	24.68±0.13
705.815	25.68±0.14	26.13±0.21	25.243.0.13	24.88±0.09	24.70±0.19
708.567	25.56±0.17	26.323-0,38	25.69±0.17	25.253.0.46	25.253.0.17
711.311	24.87±0.08	25.3040.15	25.9640.21	25.2030,12	25.2240.17
714.931	24.94±0.13	25.5840.28	25.6830.15	25.34±0.11	25.40±0.15
718.617	25.36±0.14	26.0730.30	25.0930.09	24.724,0.09	24.68±0.32
723.]06	25.75±0.14	26.0640,22	25.5640.55	25.003.0.13	25.10±0.15
728.135	24.67± 0.11	25.45±0.15	25.744-0.24	25.21±0.14	25.21±0.16
734.099	25.4940.13	25,774-0.17	25.07±0.13	24.68± 0.09	24.5940,14
741.333	25.35±0.14	25.52± 0.35	25.5640.13	25.16±0.10	25.1240.18

Table 5a, V Photometry for the Final Sample

JD 2449000.+	c31 P=15.1 $V \pm \Delta V$	c32 P=14.4 $V \pm \Delta V$	C33 P=14.0 $V \pm \Delta V$	c34 P=14.0 $V \pm \Delta V$	c35 P=13.5 $V \pm \Delta V$
2449686.375	26.4440.21	26,1540.30	25.7330,19	25.8540.27	25.603-0.11
2449694.492	25.6630.20	25.34±0.16	24.7230.11	26.5140.39	26.0440.18
2449703.471	26.2940.30	25.7730.26	25.77±0.13	25.8540.24	25.373-0.14
2449705.815	25.53±0.16	25.1240.10	25.5730.15	26.0740.31	25.71±0.18
2449708.567	25.77±0.22	25.47±0.18	25.10±0.13	26.25±0.35	25.863-0.16
2449711.311	25.97±0.29	25.63±0.18	25.22±0. 3	26.96±0.71	26.8340.18
2449714.931	26.14±0.21	26.32±0.25	25.51±0. 9	25.64± 0.37	25.2530.13
2449718.617	26.12±0.26	25.7240.25	25.96±0. 7	26.134.0.28	25,6930.14 ,
2449723,106	25.77±0.14	25.40±0.13	24.92±0 0	26.58± 0.43	26.4430.38
2449728.135	25.97±0.14	25.8340.19	25.57:10.32	26.30:10.38	25.1440.11
2449734.099	26.14±0.13	25.3430.54	25.643-O.]]	26.23:10.35	25.66± 0.17
2449741.333	25.89± 0.14	25.7330.13	25.2630.13	26.2040.33	25.5630.22

Table 5a. V Photometry for the Final Sample

JD 2449000.-I	c36 P=13.4 V ± ΔV	c37 P= 13.4 $V \pm \Delta V$	c38 P= 13.2 $V \pm \Delta V$	c39 P= 12.8 V ± ΔV	c40 P=12.5 V ± ΔV
686.375	25.904,0.14	25.84±0.24	25.82±0.27	25.76±0.18	25.9140.29
694.492	26.09±0.15	25.73± 0.16	25.56± 0.18	25.33±0.13	26.484,0.17
703.471	25.79±0.15	26.4440.24	25.47±0.22	25.8240.11	26.37± 0.19
705.815	25.7930.18	26.32± 0,24	25.61± 0.27	25.20±0.07	26.754.0.41
708.567	26.45±0.21	25.65±0.15	25.80±0.19	25.434-0.17	26.654-0.18
711.311	26.30±0.34	25.5830.18	26.18±0.25	25.853-0.19	25.72±0.18
714.931	25.31±0.12	25.6940.21	25.58±0.17	26.]34.0.12	26.4640.28
718.617	26.41±0.22	25.9830.21	25.65±0.21	25.074-0.08	26.68±0.16
723.106	26.494-0.25	25.1640.16	26.1130.21	25.604.0.17	25.963.0.17
728.135	25.244-0.13	25.8240.16	25.35+0.20	25.8840.12	26.3540.18
734.099	25.91 ±0.21	25.83±0.21	25.70±0.26	25.6130.08	26.10±0.16
741.333	25.64± 0.16	25.67± 0.20	25.6030.20	25.89± 0.18	26.3140.16

Table 5a. V Photometry for the Final Sample

JD 2449000.-i	c41 P=12.3 $V \pm \Delta V$	c42 P=12.3 V ± AV	C43 P= 11.8 $V \pm \Delta V$	c44 P=11.4 $V \pm \Delta V$	c45 P= 11.2 $V \pm \Delta V$
686.375	25.923.0.22	25.39± 0.17	25.9030.18	26.3940,17	25.6440.16
694.492	25.27±0.17	25.54±0.13	25.75± 0.17	26.10± 0.16	25.85:0.20
703.471	25.4140.26	25.7430.14	26.32:10.16	25.98±0.16	26.33± 0.22
705.815	25.13±0.11	25.434-0.14	25.77±0.15	25.93±0.13	25.8740.24
708.567	25.96±0.23	24.96±0.16	25.96±0.21	26.53±0.11	25.59±0.22
711.311	26.15±0.23	25.313-0,13	26.3630.27	26.77±0.22	25.9630.12
714.931	25.97±0.22	25.6040.18	26.84±0.24	25.9340.18	26.64±0.42
718.617	25.49± 0.16	25.47:10,12	25.79±0.09	26.35± 0.23	25.98± 0.16
723.106	26.03±0.19	25.25:10.14	26.4940.23	27.0540.25	26.22± 0.24
728.135	25.48±0.14	25.75± 0.18	26.09 ±0.23	25.8740.15	26.0730.25
734.099	25.79±0.20	25.0630.11	26.26±0.21	26,8440.28	26.0340.15
741.333	25.3930.11	25.723-0.17	25.78± 0.16	26.2740.20	25,803.0.18

Table 5a. V Photometry for the Final Sample

JD 2449000.+	c46 P=11.2 V ± ΔV	c47 P=10.6 V ± ΔV	c48 P=10.6 V ± ΔV	c49 P=10.0 V ± ΔV
686.375	26.60:10.32	26.0340.18	25.9040.25	26.863-0.54
694.492	26.353-0.23	26.1530.17	25.874-0.13	26.11±0.22
703.4'71	26.34±0.18	25.744.0.17	26.4040.39	25.9530.12
705.815	26.36:10.33	25.90:10.11	26.03:10.25	26.2140.22
708.567	26.83± 0.33	25.91± 0.21	26.37:10.21	26.9740.32
711.311	26.06± 0.27	25.36± 0.17	26.65±0.28	26.444-0.38
714.931	26.3840.27	25.85± 0.16	26.21± 0.33	26.34±0.21
718.617	26.583.0.21	26.0640.24	26.1340.37	26.46±0.23
723.106	25.9130.32	25.47±0.16	26.5130.28	26.2(240.35
728.135	26.29± 0.28	26.16± 0.25	25.7430.23	26.673-0.24
734.099	25.9430.17	25.5540.16	26.4640.37	26.11± 0.15
741.333	26.63±0.36	25.7630.21	26.2540.17	26.36± 0.30

Table 5b. I Photometry for Final Sample

JD	c01 P= 43.0	c02 P= 41.0	c03 P= 37.9	c04 P= 36.8	c05 P= 35.(I
2449000+	$I \pm \Delta I$	$I \pm \Delta I$	$I \pm \Delta I$	$I \pm \Delta I$	$I \pm \Delta I$
686.444	23.7640.08	23.263-0.05	24.4530.09	23.35±0.07	23.7540.11
705.883	23.314-0.07	23.714-0.06	23.48±0.09	23.744-0.07	24.01 ±0.14
718.686	23.42±0.10	23.05±0.05	24.1540.08	23.30± 0.08	23.8930.11
734.169	23.694-0.07	23.2340.06	23.6440.08	23.674-0.07	23.8240.12

Table 5b. I Photometry for Final Sample

JD	c06 P=34.5	c07 P= 34.5	c08 P= 32.0	c09 P=32.0	c10 P= 27,0
2449000+	$I \pm \Delta I$	$I \pm \Delta I$	$I \pm \Delta I$	$I \pm \Delta I$	$I \pm \Delta I$
686.444	23.60± 0.13	25.6930.67	23.7130.13	23.363-0.09	24.98:10.33
705.883	23.22± 0.10	24.9940.31	23.2730.10	23.41± 0.12	23.82± 0.09
718.686	23.6130.09	25.24,1 ().33	23.73,{ 0,10	23.37,10.09	24.47,10.20
734.169	23.97±0.09	25.5140.39	23,3830.09	23.5130.08	24.90± 0.28

Table 5b. I Photometry for Final Sample

JD	c11 P =25.7	c12 P= 24.7	c13 P= 24.4	c14 P=23.9	c15 P= 23.4
2449000-i	I + A l	1:1 Al	$I \pm \Delta I$	$I \pm \Delta I$	I ± Al
(X6.444	24.10±0.12	24.2240.41	24.0540.10	24.75±0.13	23.8330.12
705.883	23.82±0.09	24,0740,10	24.6630.15	24.4330.12	23.7430.13
718.686	24,343-0.13	24.69± 0.13	24.43±0.13	24.24±0.09	23.45± 0.10
734.169	23.85±0.08	24.8830.19	23.8930.08	24.04±0.12	23.7840.27

Table 5b. I Photometry for Final Sample

JD	c16 P =21.6	c17 P=21.4	c18 P= 20.8	c19 P=19.8	c20 P=19.5
2449000+	13. Al	1:1 Al	1:1 Al	$I \pm \Delta I$	$I \pm \Delta I$
686.444	24.5340.16	24.47±0.08	24.6330.15	24.3530.09	24.6430.19
705.883	24.64 ±0.12	24.4230.10	25.2240.17	24.22± 0.14	24.41±0.13
718.686	24.26± 0.12	24.5340.08	25.3340.18	24.0540.08	23.93± 0.20
734.169	24.87:10.16	24.4940.10	24.9930.10	24.7040.09	24.4240.13

Table 5b. *I* Photometry for Final Sample

JD	c21 P= 19.0	c22 P= 17.5	c23 P=16.9	c24 P=16.1	c25 P= 16.1
2449000+	1 ± Al	*I* ± Δ*I*	*I* ± Δ*I*	*I* ± Δ*I*	*I* ± Δ*I*
686.444	24.79 ±0.20	24.083.0.15	25.33±0.28	24.64±0.16	24.5940.15
705.883	24.38±0.15	24.21 ±0.11	25.573-0.25	25.09± 0.18	24.66± 0.14
718.686	24.43±0.15	23.97±0.12	25.5340.30	24.65±0.39	23.2840.39
734,169	24.14±0.11	24.44±0.16	25.3540.23	24.723-0.16	24,5040.11

Table 5b. *I* Photometry for Final Sample

JD	c26 P= 16.0	c27 P= 15.8	c28 P=15.4	c29 P= 15.2	c30 P= 15.2
2449000+	1 ± Al	*I* ± Δ*I*	1 ± Al	*I* ± Δ*I*	*I* ± Al
686.444	24.4140.14	24.8330.20	24.37± 0.14	24.213.0.14	24.84:10.22
705.883	24.64:10.16	24.8830.19	24.4730.14	24.15:10.18	24.1440,12
718.686	24.68:10.14	24.9130.19	24.3540.11	23.99± 0.12	24.16:10.12
734,169	24.45:10.13	24.8040.17	24,3040.13	24.01±0.10	24.10± 0,11

Table 5b. *I* Photometry for Final Sample

JD 2449000-i	c31 P= 15.1 $I \pm \Delta I$	c32 P= 14.4 14 A1	c33 P= 14.0 $I \pm$ A1	c34 P=14.0 $I \pm \Delta I$	c35 P=]3.5 $I \pm$ A1
686.444	25.5230.20	25.42±0.75	24.3830.17	25.424-0.26	24.67±0.19
705.883	24.80 ±0.14	24.5540,14	24.1540.14	25.93 ±0.58	. . .
718.686	. . .	24.8240.17	24.29,10.16	25.8130.43	24.70±0.18
734.169	25.2930.21	24.79± 0.18	24.09:10,14	25.72±0.48	24.80+0.11

Table 5b. *I* Photometry for Final Sample

JD 2449000-I	c36 P= 13.4 $I \pm \Delta I$	c37 P= 13.4 $I \pm \Delta I$	c38 P= 13.2 $I \pm \Delta I$	c39 P=12.8 $I \pm \Delta I$	c40 P= 12.5 13 A1
686.444	25.0740.17	24.9740.22	24.7730.49	25.03± 0.20	25.20,10.24
705.883	25.16±0.28	24.76± 0.45	24.81± 0.24	24.49± 0.12	25.6230.23
718.686	24.72± 0.1(;	25.1740.29	24.55:40.21	24.61± 0.12	25,5930.27
734.169	25.10,{ 0.22	25.1 1± 0.21	24.93:10.22	24.6240.10	25.24,10.19

Table 5b. *I* Photometry for Final Sample

JD	c41 P=12.3	c42 P= 12.3	c43 P=11.8	c44 P= 11.4	c45 P= 11.2
2449000+	$I \pm \Delta I$	$I \pm \Delta I$	1 ± Al	$I \pm \Delta I$	$I \pm$ Al
686.444	24.9040.20	24.90,10.28	25.043-0.24	25.8530.18	24.78:10.14
705.883	24.80±0.21	24.873.0.23	25.0730.15	25.32±0.20	25.0030.26
718.686	25.033-.0.22	25.'2540.48	24.9940.17	25.2640.19	25.0640.18
734.169	25.28±0.24	24.72,10.16	24.914-0.14	25.584.0.31	25.2540.21

Table 5b. *I* Photometry for Final Sample

JD	c46 P=11.2	c47 P=10.6	c48 P= 10.6	c49 P= 10.0
2449000+	$I \pm \Delta I$	1:1 A1	1:1 A1	$I \pm \Delta I$
686.444	26.00:10,59	25.21:10.36	25.44:10.54	25.43± 0.44
705.883	25.97± 0.81	25.49:10.38	26.04±0.86	25.15± 0.44
718.686	26.8541.94	25.47:10.29	25.4130.33	...
734.169	26.37± 0.87	25.0240.20	25.6440.40	25.54± 0.60

‘1’able 6. Positions and Periods for Cep heid Variables

Star	Chip	x	y	R.A.(2000) h m s	Dec. (2000) 0 ′ ″	P (days)	Notes
c01	4	138.63	111.42	10 43 52.92	11 41 15.20	43.0±1.0	
c02	1	546.13	125.85	10 43 51.54	11 41 20.40	41.0± 1.0	
c03	4	462.26	583.11	10 43 50.83	11 40 27.44	37.9± 1.0	
c04	4	391.30	111.69	1 0 43 53.58	11 40 52.17	36.8± 1.0	
c05	2	126.93	218.77	10 43 54.05	11 41 41.04	35.0: }-1 .0	
c06	3	561.55	711.47	10 43 58.07	11 40 49.64	34.5±1.0	
c07	2	382.20	552.03	10 43 55.41	11 42 17.44	34.5:10.5	1
c08	2	134.01	27’7.87	10 43 54.39	11 41 43.99	32.03- 2.0	
c09	2	475.83	240.19	10 43 53.23	11 42 13.48	32.0± 1.0	2
c1o	2	452.99	637.15	10 43 55.74	11 42 27.26	27.0± 0.5	3
c11	4	248.06	584.83	10 43 50.26	11 40 47.00	25.740.8	
c12	3	150.05	432.48	10 43 54.83	11 40 55.89	24.741.5	
c13	4	785.11	379.89	10 43 52.94	11 40 52.94	24.4± 0.3	
C14	4	736.44	437.25	1 0 43 52.46	11 40 07.86	23.930.2	4
c15	3	606.41	359.57	10 43 57.46	11 41 20.49	23.4±0.2	
c16	3	255.73	617.34	10 43 55.98	11 40 43.28	21.6± 0.2	
c17	1	463.78	254.91	10 43 51.62	11 41 27.22	21.440.2	5
c18	1	469.15	455.80	1 0 43 51.37	11 41 35.56	20.8:0,2	
c 19	4	402.05	342.50	1 0 43 52.17	11 40 42.26	19.8± 0.2	
c20	1	083.5(;	195.64	10 43 52.77	11 41 31.54	19.54 -().2	
c21	3	614.73	584.73	10 43 58.11	11 41 00.34	19.0,10.2	6

'J'able 6-Continued

Star	Chip	x	Y	R.A.(2000) 11 m s	D ec.(2000) ° ′ ″	P (days)	Notes
c22	2	789.28	250.71	10 43 52.55	11 42 42.23	17.530.1	7
c23	4	781.84	376.43	10 43 52.96	11 40 06.32	16.941.0	8
c24	4	684.23	404.73	10 43 52.53	11 40 14.10	16.13-0.1	
c25	2	749.20	291.81	10 43 52.81	11 42 40.26	16,13-0,2	
c26	3	247.31	314.20	10 43 55.)1	11 41 10.46	16.0± 0.1	
c27	2	053.00	204.09	10 43 54.16	11 41 33.78	15.840.1	9
c28	3	183.71	457.75	10 43 55.11	11 40 54.90	15.430,3	
c29	3	201.90	183.86	10 43 54.48	11 41 20.48	15.230.2	
c30	2	477.18	242.98	10 43 53.25	11 42 13.70	15.240.1	10
c31	4	087.68	674.51	10 43 49.30	11 40 58.07	15.1± 0.2	
c32	2	756.19	570.06	10 43 54.51	11 42 51.95	14.430.1	
C33	3	101.11	367.81	10 43 54.36	11 40 59.81	14.03-0.2	
C34	2	630.41	576.08	10 43 54.89	11 41 25.17	14.04-0.1	11
c35	3	132.76	102.23	10 43 53.84	11 41 25.17	13.5±0.3	
c36	4	642.59	159.86	10 43 53.94	11 40 27.38	13.4± 0.2	
C37	4	321.55	102.64	10 43 .53.45	11 40 58.89	13.440.2	12
c38	2	215.43	117.08	10 43 53.18	11 41 44.95	13.230.1	
c39	1	770.97	340.06	10 43 50.65	11 41 25,27	12.840.4	
c4o	3	370.67	628.81	10 43 56.72	11 40 46.72	12.530.2	
("41	3	413.95	288.78	10 43 56.08	11 41 19.22	12.340.1	
c42	3	224.95	061.97	10 43 54.30	11 41 32.44	12.340.1	13

Table 6- Continued

Star	Chip	X	y	R.A.(2000)	Dec.(2000)	P	Notes
				h m s	° ′ ″	(days)	
c43	3	328.75	648.46	10 43 56.51	11 40 43.31	11.8±0.2	
c44	4	310.73	369.75	10 43 51.76	11 40 49.53	11.4±0.3	
c45	3	564.20	678.34	10 43 58.05	11 40 50.27	11.2±0.2	14
c46	2	209.64	541.90	10 43 55.82	11 42 01.42	11.2±0.2	15
c47	3	436.49	683.77	10 43 57.27	11 40 44.33	10.6±0.1	
c48	3	680.53	517.58	10 43 58.34	11 41 09.04	10.6±0.1	
c49	3	589.75	496.76	10 43 57.72	11 41 07.36	10.0±0.1	

[1] c07: very high background - poor light curve - excluded from PL fit.

[2] c09: low amplitude, flat bottomed lightcurve - photometry contaminated by bright blue companion - excluded from PL fit. well separated from c30.

[3] c10: high background - low quality light curve.

[4] c14: elongated image - consistently rejected by DAOPHOT - DoPHOT used.

[5] c17: image elongated - red companion - very red color - excluded from PL fit.

[6] c21: one deviant point in light curve.

[7] c22: close to edge of frame - some deviant phase points.

[8] c23: clumpy background - low quality light curve.

[9] c27: very close to edge of frame.

[10] c30: close to but well separated from c09.

[11] c34: background high.

[12] [illegible]

Table 7. Periods/Mean Magnitudes for Cepheid Variables

Star	P (days)	log P	$<V>_{in}$	$<V>_{ph}$	$<I>_{in}$	$<I>_{ph}$	$<I>_{\Delta I}$
c01	43.0	1.633	24.42	24.42	23.52	23.49	23,46
c02	41.0	1.613	24.41	24.39	23.29	23.31	23.42
C03	37.9	1,579	24.95	24.95	23.86	23.81	23.91
C04	36.8	1.566	24.38	24.36	23.50	23.52	23.47
c05	35.0	1.544	25.00	24.99	23.86	23.86	23.86
c06	34.5	1.538	24.57	24.65	23.56	23.56	23.58
c07	34.5	1.538	25.92	25.90	25.32	25.31	25.33
c08	32.0	1.505	24.44	24.47	23.50	23.48	23.53
c09	32,0	1.505	23.96	23.97	23.41	23.41	23.37
c10	27.0	1.431	26.18	26.21	24.78	24.72	24.64
c11	25.7	1.409	24.96	25.04	24.01	24.05	24.15
c12	24.7	1.393	25.42	25.42	24.42	24.38	24.45
c13	24.4	1.387	24.97	25.03	24.21	24.34	24.31
c14	23.9	1.378	25.76	25.75	24.33	24.35	24.35
c15	23.4	1.369	24.79	24.76	23.69	23.63	23.64
c16	21.6	1.334	25.81	25.77	24.55	24.52	24.55
c17	21.4	1.330	26.63	26.63	24.48	24.49	24.45
c18	20.8	1.318	26.32	26.41	25.01	25.06	24.94
c19	19.5	1.290	25.26	25.28	24.29	24.31	24.26
c20	19.5	1.290	25.60	25.47	24.32	24.30	24.32
c21	19.0	1.279	25.49	25.47	2.4.41	24.35	24.43

'1'able! 7- Continued

Star	P (days)	log]'	$< v >_{in}$	$< v >_{ph}$	$< I >_{in}$	$< I >_{ph}$	$< I >_{\Delta I}$
c22	17.5	1.243	25.40	25.45	24.16	24.23	24.30
c23	16.9	1.228	26.56	26.47	25.44	25.45	25.42
c24	16.1	1.207	25.70	25.65	24,75	24.87	24.65
c25	16.1	1.207	25.77	25.72	24.49	24.54	24.61
c26	16.0	1.204	25.27	25.22	24.53	24.56	24.64
c27	15.8	1.199	25.73	25.75	24.85	24.86	24.71
c28	15.4	1.188	25.41	25.44	24.37	24.40	24.52
c29	15.2	1.182	25.02	25.06	24.08	24.15	24.22
c30	15.2	1.182	24.99	25.03	24.27	24.38	24.38
c31	15.1	1.179	25.94	25.93	25.16	25.13	25.22
c32	14.4	1.158	25.60	25.60	24.85	24.92	24.90
c33	14.0	1.146	25.35	25.33	24.22	24.25	24.08
c34	14.0	1.146	26.16	26.18	25.70	25.59	25.66
c35	13.5	1.130	25.67	25.73	24.72	24.71	24.76
c36	13.4	1.127	25.87	25.95	25.00	24.99	25.09
c37	13.4	1.127	25.76	25.77	24.99	25.03	24.89
c38	13.2	1.121	25.68	25.70	24.75	24.75	24.76
c39	12.8	1.107	25.58	25.60	24.67	24.73	24.78
c40	12.5	1.097	26.26	26.27	25.39	25.36	25.39
c41	12.3	1.090	25.62	25.69	24.98	24.94	25.06
c42	12.3	1.090	25.40	25.38	24.91	24.89	24.96

Table 7- Continued

Star	P (days)	logP	$< V >_{in}$	$< V >_{ph}$	$< I >_{in}$	$< I >_{ph}$	$< I >_{\Delta I}$
c43	11.8	1.072	26.00	26.14	25.00	24.99	25.11
c44	11.4	1.057	26.27	26.29	25.47	25.48	25.60
C45	11,2	1.049	25.96	25.99	25.01	25.04	25.04
c46	11.2	1.049	26.32	26.30	26.24	26.19	26.23
c47	10.6	1.025	25.80	25.75	25.29	25.25	25.'25
C48	10.6	1.025	26.17	26.21	25.60	25.63	25.67 . . .
c49	10.0	1.000	26.35	26.39	25.36	25.43	25.37

Table 8. Error Budget

	Source of Uncertainty	Error	Comment
(a)	F555W calibration	± 0.04	
(b)	F814W calibration	± 0.04	
(c)	V photometry zero	± 0.03	
(d)	I photometry zero	± 0.04	
(A)	cumulative error V	± 0.05	(errors uncorrelated)
(B)	**cumulative error I**	± 0.06	
(e)	PL fit (V)	± 0.06	
(f)	PL fit (I)	± 0.05	
(C)	True Modulus	± 0.16	due to A,B,e,f (errors correlated)
(d)	LMC Modulus	± 0.10	
(D)	**Total Uncertainty**	± 0.19	

REFERENCES

Aaronson, M., & Mould, J. 1983, ApJ, 265, 1

Baade, W., & Swope, H.H. 1963, AJ, 68, 435

Baade, W., & Swope, H.H. 1965, AJ, 70, 212

Böhm-Vitense, E. 1990, ApJ, 324, L27

Burkhead, M.S., & Hutter, D.J. 1981, AJ, 86, 523

Cardelli, J. A., Clayton, G.C., & Mathis, J.S. 1989, ApJ, 345, 245

Ciardullo, R., Jacoby, G.H., & Ford, H.C. 1989, ApJ, 344, 715

de Vaucouleurs, G. 1975, in Galaxies and the Universe (Stars and Stellar Systems X) eds. Sandage, Sandage, & Kristian, U. Chicago Press. p577

Faber, S.M. *et al.*, ApJS, 69, 763

Feldmeir, J. J., Ciardullo, R., & Jacoby, G.H. 1996, ApJ, (submitted)

Ferrarese, L. *et al.* 1996, ApJ, 464, 568

Freedman, W.L. 1988, ApJ, 326, 691

Freedman, W.L., & Madore, B.F. 1990, ApJ, 365, 186

Freedman, W.L. *et al* 1990, ApJ, 355, L35

Freedman, W.L. *et al.* 1994a, ApJ, 427, 628

Freedman, W.L. *et al.* 1994b, Nature, 371, 757

Harris, W. 1990, PASP, 102, 966

Hill, R.J. *et al.* 1996, ApJ (in press)

Holtzman, J.A. *et al.* 1995, PASP, 107, 156

Huchra, J.P., & Geller, M. 1982, ApJ, 257, 423

Jacoby, G.]]. *ct al.* 1992, PASP, 104, 599

Kelson, D. *ct al.* 1996, ApJ, 463, 26

Kennicutt, R.C., Freedman, W.],., & Mould, J.R. 1994, AJ, 110, 1476

Kenney, J.D.P. *ct al.* 1992, ApJ, 395, 1,79

Lafler, J., & Kinman, T.D. 1965, ApJS, 11, 216

Madore, B.F. 1985, in Cepheids: Theory and Observation (1 AU (colloquium 82), cd. Madore (Cambridge University Press), p 166

Madore, B.F., & Freedman, W.L. 1991, }'ASI', 103, 933

Mould, J. *ct al.* 1995, ApJ, 449, 413

Nemec, J. M., & Lutz, 'I'. It. 1993, in New Perspectives on Stellar Pulsation and Pulsating Variable Stars (1 All Colloquium 139) eds Nemec and Matthews (Cambridge University Press) p 31

Phillips, M.M. 1993, ApJ, 413, L105

Rawson, D.M. *ct al. 1996,* ApJ (in press)

Rubin, V.C., Ford, W. K., & Peterson, C.J. 1975, ApJ, 199, 39

Saha, A., & Hoessel, J.G. 1990a, ApJ, 330, 579

Saha, A., & Hoessel, J.G. 1990b, AJ, 99, 97

Saha, A. *ct al.* 1994, ApJ, 425, 14

Saha, A. *ct al.* 1995, ApJ, 438, 8

Saha, A. *ct* al. 1996, ApJ (in press)

Sandage, A. *ct al.* 1996, ApJ, 460, L15

Sandage, A,, & Bedke, J. 1994, in The Carnegie Atlas of Galaxies, Carnegie Institution of Washington, Washington DC

Sandage, A., & Tammann, G. 1981, in A Revised Shapley-Ames Catalogue of Bright Galaxies, Carnegie institution of Washington, Washington 11~

Schechter, 1'.1,., Mateo, M., & Saha, A. 1993, PASP, 105, 1342

Schmidt, B.P. *et al.* 1994, ApJ, 432?, 42

Schneider, S.E. 1985, ApJ, 288, L33

Schneider, S.E. 1989, ApJ, 343, 94

Silbermann, N.A. *et al.* 1996, ApJ (in press)

Stellingwerf, R.F. 1978, ApJ, 224, 953

Stetson, P.B. 1990, PASP, 102, 932

Stetson, 1'.11.1994, AJ, 106, 205

Tanvir, N.R. *et al.* 1995, Nature, 377, '27

Tonry, J.L. *et al.* 1991, ApJ, 373, L1

Tonry, J .1,. *et al.* 1996, ApJ (submitted)

Wayman, P.A., Stift, M. J., & Butler, C.J. 1984, A& AS, 56, 169

Welch, 1).1,., & Stetson, P.B. 1993, AJ, 105, 1813

Wells, L.A. *et al.* 1994, AJ, 108, 2223

This manuscript was prepared with the AAS LaTeX macros v4.0.

Fig. 1.- A V image of NGC 3351 with the Hubble Space Telescope field marked. It is adapted from 3 10-minute CCD frames taken with the Las Campanas 2.5m du Pont telescope on May 31, 1995. The PC chip covers the smallest field (chip1). Moving anti-clockwise, the other 3 WF2 fields correspond to chips 2,3 and 4.

Fig. 2.- Sampling variance of light curves from data taken using the exposure sequence given in Table 1.

Fig. 3.- 3(a) Chip 1 Finding Chart. The locations of the NGC 3351 Cepheids on chip 1 (Planetary Camera) of the WFPC2 instrument are marked. The field of view is 36 x 36 arcsec. The Cepheids are circled and labeled with their identification number from Table 6., 3(b) Chip 2 Finding Chart. The locations of the NGC 3351 Cepheids on chip 2 (Wide Field Camera) of the WFPC2 instrument are marked. The field of view is 1.3 x 1.3 arcmin., 3(c) Chip 3 Finding Chart. The locations of the NGC 3351 Cepheids on chip 3 (Wide Field Camera) of the WFPC2 instrument are marked. Scale similar to Figure 3(b)., 3(d) Chip 4 Finding Chart. The locations of the NGC 3351 Cepheids on chip 4 (Wide Field Camera) of the WFPC2 instrument are marked. Scale similar to Figure 3(b).

Fig. 4.- Cepheids on Chip 1. Finding charts for individual Cepheids located on chip 1. The field of view is 4.5 arcsec (100 pixels) on a side. The Cepheids are circled and labeled with their identification numbers as listed in 'Table 6.

Fig. 5.- Cepheids on Chips 2, 3 and 4. Finding charts for individual Cepheids located on chips 2, 3 and 4, The field of view is 10 arcsec (100 pixels) on a side. The Cepheids are circled and labeled with their identification numbers as listed in Table 6.

Fig. 6.- A histogram of periods of the NGC 3351 Cepheid variable stars (solid lines). It is compared with histograms made from similar lists of Cepheids found in M 31 (Baade and Swope 1963,1965) (dotted lines) and the Magellanic Cloud calibrating sample (Madore 198:))

(dashed lines) . Each list is normalized to an integrated total of 50 stars.

Fig. 7.- ALLFRAME V magnitude light curves for each Cepheid variable. The adopted period is shown along with a characteristic, uncertainty range as reported by A LLFRAME for a typical point.

Fig. 8.- An *I*, ***V-I*** color magnitude diagram constructed using the mean photometric magnitudes of all stars measured in ALLFRAME. Cepheid arc shown as filled circles and populate the instability strip. Internal reddening within the galaxy may contribute substantially to the distribution of the points.

Fig. 9.- The V 1'1, relation for the sample of Cepheids. Four stars, c07, c09, cl 7 and c46 are not included (see text). The solid line represents the best unweighted fit using phase weighted mean magnitudes and corresponds to a modulus of 30.38±0.06 msg. The dashed lines drawn at ±0.54 mag reflect the finite width of the Cepheid instability strip and thus the expected 2σ scatter around the best fitting PL relation.

Fig. 10.- The *I* }'1, relation for the sample of' Cepheids. Four stars, c07, c09, c17 and c46 arc not included (see text). The solid line represents the best unweighted fit. Phase weighted mean *I* magnitudes (computed using phase information and magnitudes from the V light curves (see text)) arc used. The apparent modulus is 30.2330.05 mag. The clashed lines drawn at ±0.36 mag reflect the finite width of the Cepheid instability strip and thus the expected intrinsic 2σ scatter around the best fitting PL relation.

Fig. 11.- Magnitude residuals in *I* arc plotted against magnitude residuals in *V* from the corresponding PL relations for NGC 3351. The known limits of the Cepheid instability strip are shown by the heavy solid line. The correlation expected due to differential reddening is shown by the dotted line. Stars which scatter to the right may be subject to unusually high reddening due to dust absorption within NGC 335].